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DEVELOPMENT OF THE SASDOC COMPUTER CODE

Report No 84-286-K

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ABSTRACT

The surface wind model of the SASDOC computer program was optimized for the Pickering area. The optimization included modifications of the model itself and the input data files, and the incorporation of the microscale features of the Pickering area. These modifications enhance the time resolution of the surface wind calculation and improve the model execution time and input and output computer codes. As well, similarity equations were implemented to calculate the vertical wind profiles. The model was applied to simulate the surface wind field on seven selected time periods and the results were compared with observations. The simulated wind fields agree quantitatively with the observed values. It is recommended that vertical wind profiles be measured and used to fine tune the model.

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EXECUTIVE SUMMARY

SASDOC is a computer program used to calculate dose rates and cumulative doses of radionuclides from a release to the atmosphere. The program consists of a surface wind model which provides the surface wind field and a puff dispersion model which determines the dispersion of pollutant plumes.

In the present study, optimizations were made to the surface wind model in the SASDOC program in order to enhance the applicability of the program to the Pickering area. The optimizations included modifications of the model itself and the input data files, and the incorporation of the microscale features of the Pickering area. As well, similarity equations were implemented to calculate the vertical wind profiles.

The model was applied to simulate the surface wind fields during seven time periods on April 2 and 3, 1982 and February 9, 1984. The simulated results were compared with values observed at the Pickering Generating Station. The model successfully simulated the surface wind direction and the diurnal variation of the surface wind. However, it was less successful in simulating the magnitudes of the surface wind speed. Measurements of the vertical wind profiles in the Pickering area were recommended, as such data were unavailable for comparison with the model.

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To Mr. F.J. Kee
Director of Research

DEVELOPMENT OF THE SASDOC COMPUTER CODE

1.0 INTRODUCTION

1.1 Background

The Safety Services Dose Calculation Computer Program (SASDOC) was developed by the Public Safety Unit of the Safety Services Department (Pickering), Health and Safety Division. The program in its present version consists of two models: a surface wind model and a puff model.

The surface wind model is a prognostic, one-level, primitive equations model originally developed by Danard (1977). It takes into account the mesoscale influences of topography and surface heating. The puff model is a puff-diffusion model developed by Sheih (1978). The model includes wind shear effects and dynamic plume rise calculations. These two models are used to determine dispersion of radionuclide releases and to calculate the dose rates in the path of the plume.

The surface wind field is one of the most important factors in determining dispersion of air pollutants and calculating trajectories of pollutant plumes. It is also the input data required by the puff model in the SASDOC program. The present study deals with modifications made to the surface wind model in the SASDOC program to enhance the applicability of the program, particularly in the Pickering area. Further studies will be carried out later to deal with the puff model and the interaction between models within the SASDOC program.

1.2 Objectives and Scope of the Present Study

The major objectives of the present study were:

(1) to improve the time resolution of the surface wind calculations and to incorporate the microscale features of the Pickering area into the surface wind model,

(2) to improve the calculation of vertical wind profiles,

(3) to optimize the computer code for execution time and simplicity of input and output,

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(4) to compare model predictions with available observed data in the Pickering area.

The surface wind model being used in the SASDOC program has been tested and documented previously. However, for completeness, the model will be briefly described and given in Section 2.0. Section 3.0 presents the modifications to the original surface wind model made to meet the objectives of this study. It is followed, in Section 4.0, by a comparison between model predictions and observed wind data in the Pickering area. Concluding remarks are given in Section 5.0.

2.0 DESCRIPTION OF THE SURFACE WIND MODEL

2.1 Model Formulation

The surface wind model being used in the SASDOC program is an adaptation of the mesoscale model of Danard (1977). The principal dynamic equations in the model are a pressure tendency equation, the first law of thermodynamics and the equation of motion.

The pressure tendency equation is used to calculate the rate of change of the surface pressure. It is assumed that surface features have little influence on the mesoscale pressure field within the thermal boundary layer. Thus, by using the hydrostatic equation and the definition of potential temperature, θ, the surface pressure tendency equation may be expressed by

$$\frac{\partial \ell n p_s}{\partial t} = - \frac{g}{R\, \theta_s\, T_s} \int_0^H \frac{\partial \theta}{\partial t}\, dz \qquad (2\text{-}1)$$

where p is the atmospheric pressure, t is the time, g is the acceleration of gravity, R is the gas constant, T is the absolute temperature, H is the thermal boundary layer height and z is the height above surface. The subscript s denotes surface values.

The value of H is calculated from an equation given by Hanna (1969)

$$H = 0.75\, V_g \left[\frac{g\, \Delta\theta}{T_s\, H} \right]^{1/2} \qquad (2\text{-}2)$$

where V_g is the geostrophic wind and

$$\Delta\theta = \frac{\theta}{T} \left[-\Delta T + H(\gamma_d - \gamma) \right] \qquad (2\text{-}3)$$

ΔT is the difference between the actual surface temperature T_s and the pseudo surface temperature T_i obtained by linear extrapolation downward from 700 and 850 mb, ie,

$$\Delta T = T_s - T_i \qquad (2\text{-}4)$$

γ_d is the dry adiabatic lapse rate and γ is the free atmosphere lapse rate between the 850 and 700 mb levels.

The surface temperature is obtained from the first law of thermodynamics which is given as

$$\frac{\partial \theta}{\partial t} = - \vec{V} \cdot \nabla \theta_s + K_t \nabla^2 \theta_s + Q \qquad (2\text{-}5)$$

Here, $\vec{V}$ is the surface wind, ∇ is the horizontal gradient operator, K_t is the horizontal thermal conductivity and Q is the diabatic rate of surface heating. In the present study, Q is given by

$$Q = \frac{\theta_s}{T_s} \frac{\Delta T}{\tau} \qquad (2\text{-}6)$$

where τ is the time interval over which the heating is added. Thus, Q depends upon the surface temperature change. In other words, the surface heating (or cooling) will change the surface temperature by an amount of ΔT in time τ .

The surface wind is obtained from the equation of motion:

$$\frac{\partial \vec{V}}{\partial t} = -\vec{V} \cdot \nabla \vec{V} - [g \nabla z_s + R T_s \nabla \ell n p_s] - f \vec{k} \times \vec{V} + \vec{F} + K_m \nabla^2 \vec{V} \qquad (2\text{-}7)$$

where z_s is the terrain height above mean-sea-level, f is the Coriolis parameter, $\vec{k}$ is the vertical unit vector, $\vec{F}$ is the surface friction and K_m is the horizontal momentum viscosity.

The magnitude of the surface friction is determined from the empirical formula given by Deardorff (1972)

$$F = \sqrt{2}\, c\, C_D\, V^2\, h^{-1} \qquad (2\text{-}8)$$

where c is a stability constant with values of 2.8 for stable and neutral conditions and 1.0 for extremely unstable conditions. C_D is the drag coefficient obtained from the surface roughness length z_o using the relationship suggested by Sutton (1953)

$$C_D = k_o^2 \, [\ell n (h_A / z_o)]^{-2} \qquad (2\text{-}9)$$

Here, k_o is the von Karmann constant taken as 0.4 and h_A is the anemometer height of 10 m. h is the momentum boundary layer height.

2.2 Method of Solution

The study domain is divided into a grid network. The governing equations are solved numerically by finite differencing methods at each grid point. More specifically, the so-called "leap-frog" method is used for the calculation except for θ and $\ln p_s$, in which the forward time and upstream space differences are used because these two terms change with time.

The meteorological input data for this model consist of the sea-level wind, temperature and pressure, the 850 mb and 700 mb heights and temperatures and the 850 mb geostrophic winds at a reference station. For a lakeshore environment, the reference station should be sufficiently far inland from a shoreline so that the input data are unaffected by the land-lake discontinuity.

The initial geostrophic wind is computed assuming a balance between pressure gradient, Coriolis and friction forces. This initial geostrophic wind is then used to compute a balance initial wind everywhere in the study domain including effects of stability and horizontal variations in surface roughness. The temperature and pressure fields are modified by varying topography and the winds are adjusted dynamically to the new pressure field.

In summary, the algorithm is generated starting from initial values of θ, T_s, $\ln p_s$, and $\bar{V}$. New values of θ, $\ln p_s$ and $\bar{V}$ are then predicted by Equations (2-1), (2-4) and (2-7). Figure 1 gives a flow chart of the algorithm.

3.0 MODIFICATION OF THE SURFACE WIND MODEL

3.1 Local Terrain Features

Figure 2 displays the location of the Pickering area with the study domain outlined by a square. There are 25x25 grid points in the domain with a grid size of 1 km. The 1 km grid size was chosen in order to take into account the microscale effects on the wind field. The local terrain heights for each grid point were obtained from the Mercator Coordinate topographical maps. They are shown in Figure 3.

It can be seen that the main physical features of the study domain are a water body (Lake Ontario) and high lands to the northwest. The ravines of Duffin Creek and Rouge River are also noted in the figure. The terrain height increases gradually from 76 m above mean-sea-level at the shoreline area to over 250 m at about 15 km inland from the lake. These terrain heights are necessary for the calculation of the horizontal pressure gradient forces.

Figure 4 displays the surface roughness length over the study domain. The roughness length is a measure of the aerodynamic roughness of the surface. It depends upon the surface features. In the present study, the surface roughness length is assumed to be 0.1 cm over the water but varied over the land according to the vegetation cover and building configurations. Values used for the land surface ranged from 10 cm for thick grasslands to 30 cm for forest; from 50 cm for

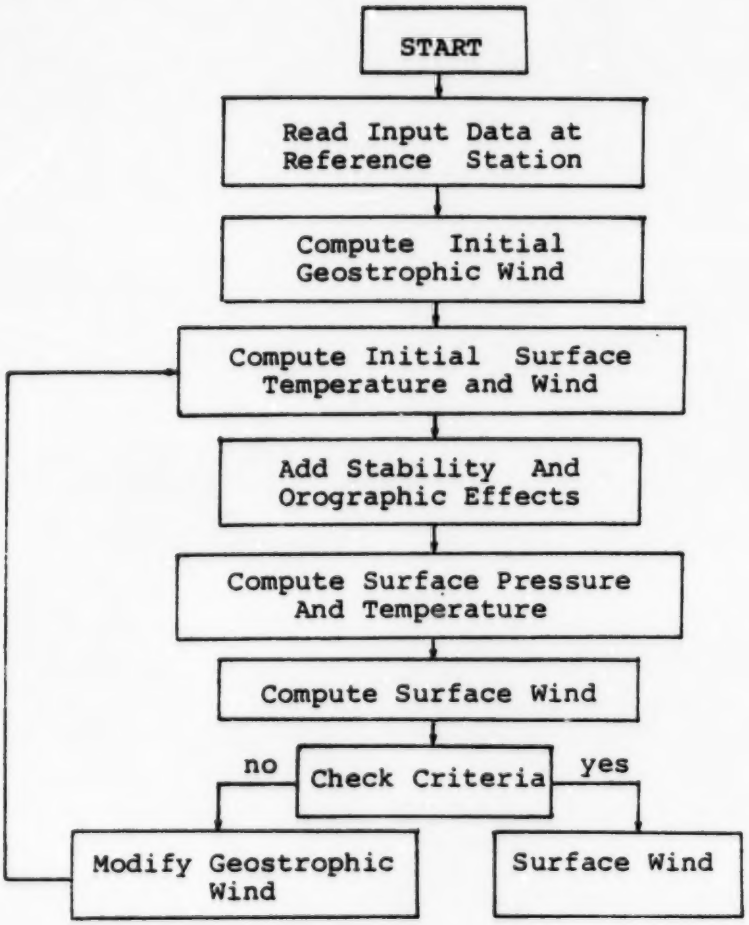

FIGURE 1

FLOW CHART OF SURFACE WIND CALCULATION

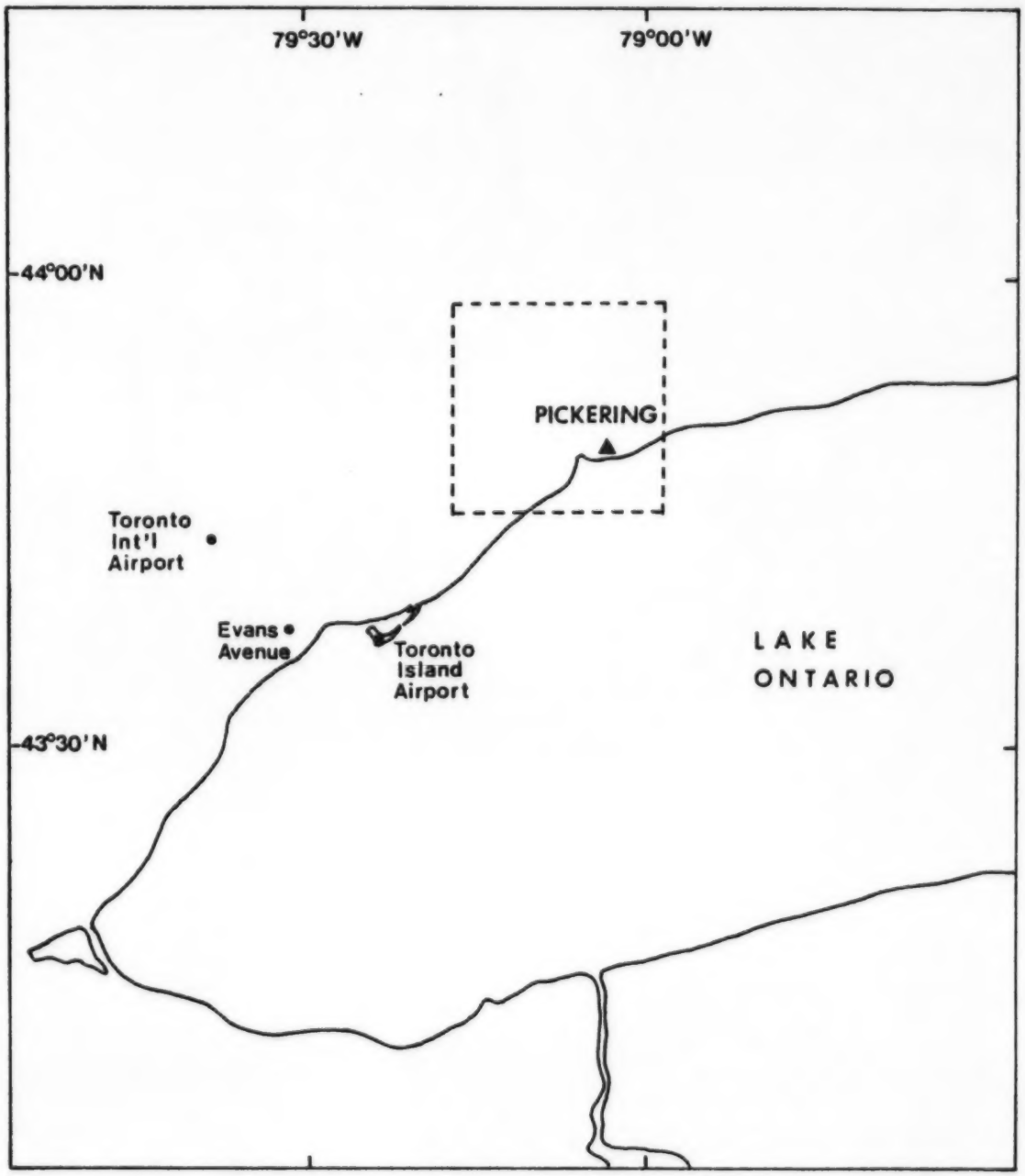

FIGURE 2

THE LOCATION OF THE PICKERING AREA

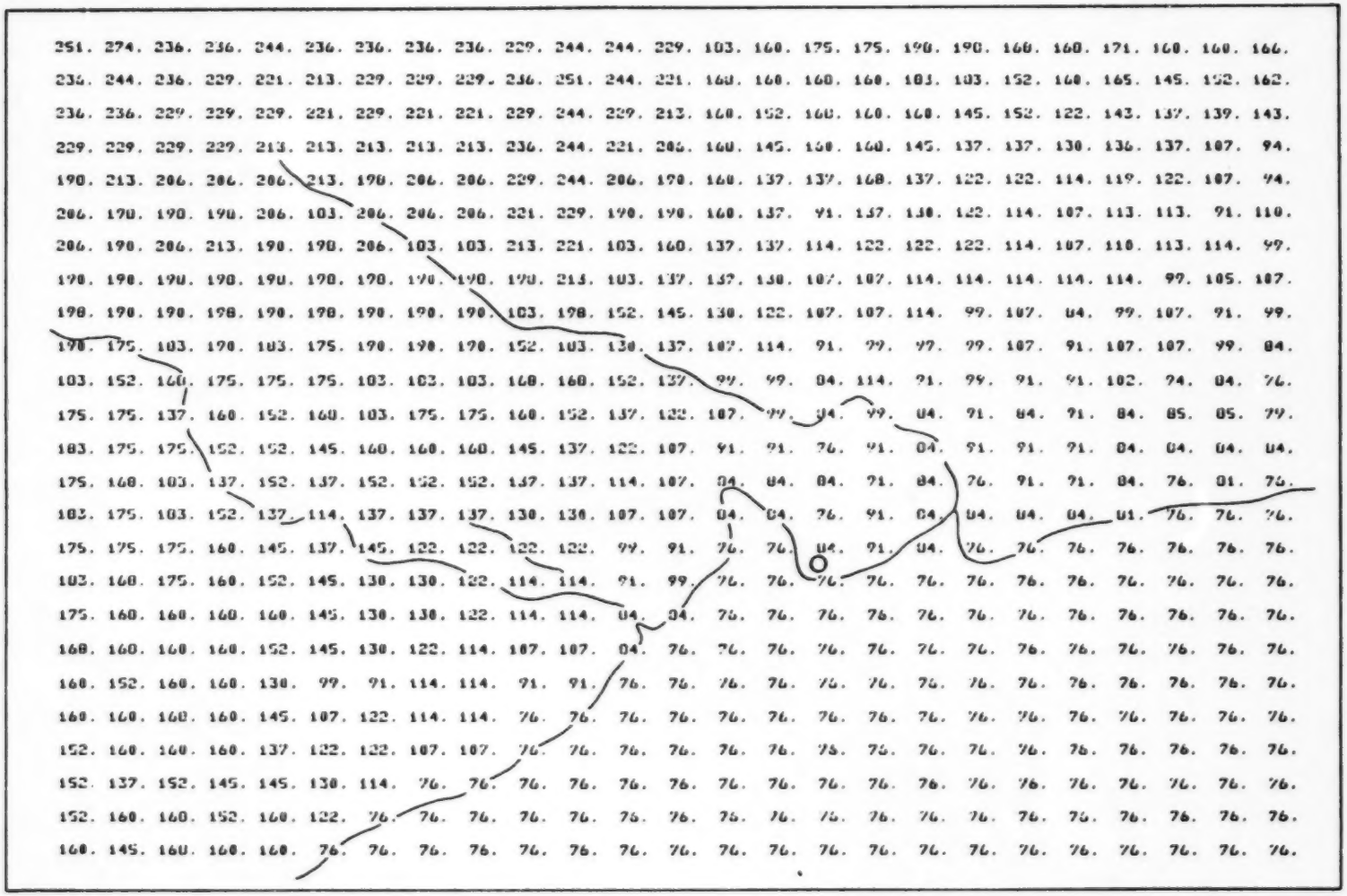

FIGURE 3

THE TERRAIN HEIGHTS (m) OF THE PICKERING AREA

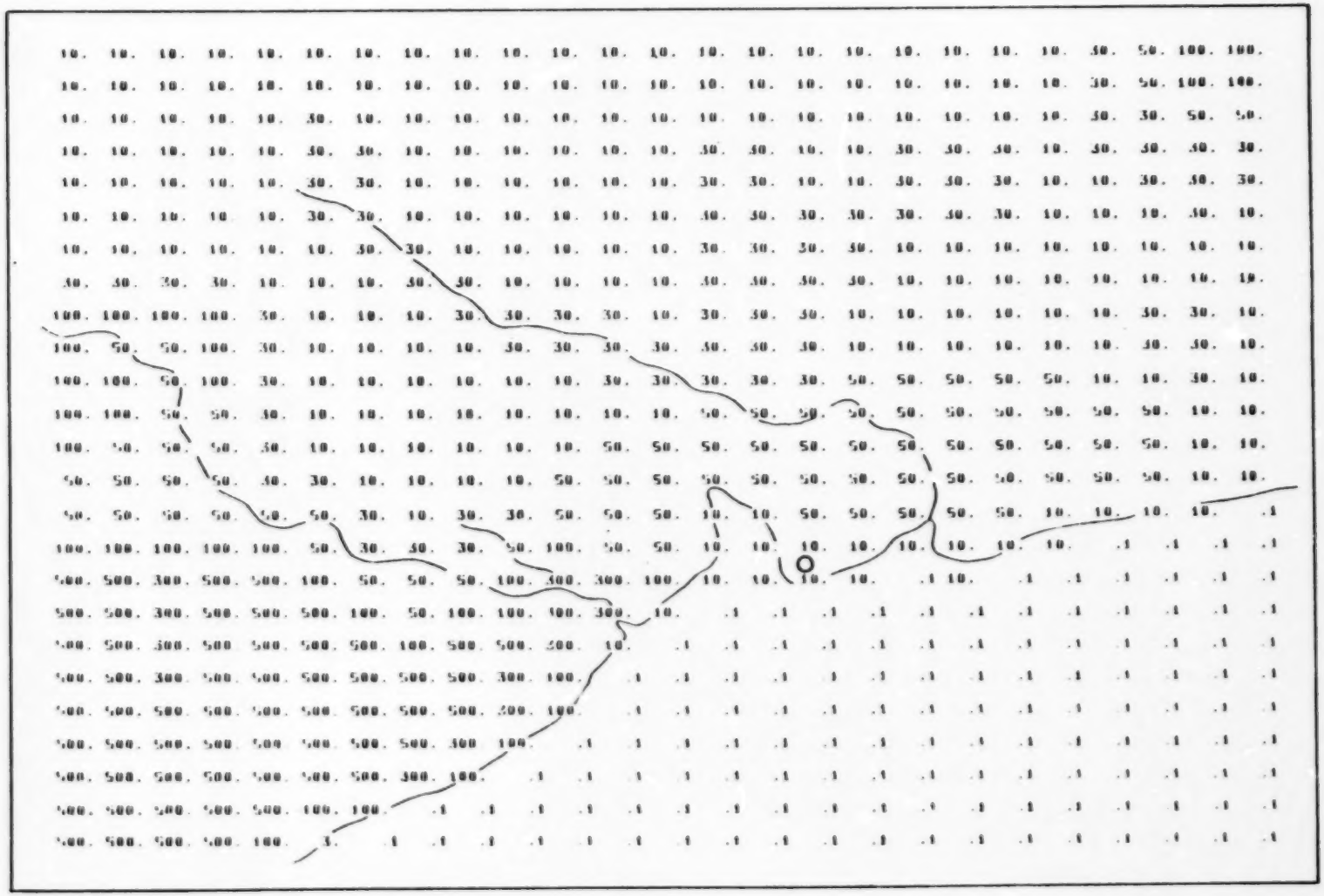

FIGURE 4

THE SURFACE ROUGHNESS LENGTHS (cm) OF THE PICKERING AREA

low buildings of about 4 m in height and 100 cm for medium buildings of about 20 m in height to 500 cm for tall buildings, with building height over 100 m.

As seen from Figure 4, the surface within the study domain is rather non-homogeneous, especially along the shoreline area. Large roughness lengths in response to high building areas are located to the southwest sector of Pickering NGS. This non-homogeneous surface feature would be expected to influence the air flow pattern in the Pickering area.

3.2 Vertical Wind Profiles

The vertical wind profiles are one of the inputs required by the puff model. Practically, these wind profiles can be obtained by PIBAL soundings. However, it would be desirable to predict the vertical wind profiles from the information on surface winds.

Generally, the wind speed increases quite rapidly in the lowest levels of the atmosphere and then changes slowly with increasing height. The wind direction, on the other hand, is nearly constant with elevation up to about 100 m. Similarity analyses indicate that the winds in the lower atmosphere can be expressed by a log-linear profile (see for example, Blackadar, 1963; Swinbank, 1964). In the present study, the wind speed at height z above the surface, U, is determined by the similarity equations of Deardorff (1972). They are

$$U = \frac{u_*}{k_o} \left[\ell n \left(\frac{z}{z_o} \right) + 4.7 \frac{z}{L} \right] \qquad (3\text{-}1)$$

for stable and neutral conditions (ie, $L \geq 0$) and

$$U = \frac{u_*}{k_o} \left[\ell n \left(\frac{z}{z_o} \right) - A \right] \qquad (3\text{-}2)$$

where

$$A = \ell n \frac{(1+\xi)^2}{2} + 2 \ell n \frac{(1+\xi)}{2} - 2 \tan^{-1} \xi + \frac{\pi}{2} \qquad (3\text{-}3)$$

for unstable conditions (ie, $L < 0$. u_* is the friction velocity and L is the Monin-Obukhov length, given by

$$L = [u_*^3 \, \theta_s \, C_p \, \rho] / [k_o \, g \, Q] \qquad (3\text{-}4)$$

ρ is the air density, C_p is the specific heat of dry air at constant pressure, and

$$\xi = [1 - 15 \frac{z}{L}]^{1/4} \qquad (3\text{-}5)$$

Of the variables required for these wind profile calculations, the surface heat flux Q is available from Equation (2-6) and the friction velocity u_* may be given by

$$u_* = C_D V \qquad (3\text{-}6)$$

where C_D, the drag coefficient, is calculated by Equation (2-9). However, an iteration procedure is necessary for the solutions since some variables are interrelated.

3.3 Optimization of the Computer Code

The surface wind model was originally a research model used to scrutinize the influences of physical terrain features on atmospheric motions. It was designed to be expanded and modified to include the calculation of other meteorological variables of interest. These modifications lead to longer execution time and larger storage space requirements during the calculation. Therefore, optimization of the computer code is necessary if the model is to be used for routine operational purposes.

The surface wind model consists of one main program and thirteen subprograms. The main program controls the execution of all the subprograms. In addition, the main program provides values for constants; sets up the study domain; defines input data; sets the starting time and termination time of the prediction; performs commands to calculate initial wind and temperature fields; performs commands to predict surface pressure, wind and temperature fields; performs commands to calculate vertical wind profiles; and performs commands to print output results. Each of the calculation loops is executed by the subprograms.

To optimize the computer code, modifications were first made to the input data subprograms, READ1, READ2 and READ3 so that each of these three subprograms is able to provide unique input data.

READ1 provides basic input data which will not change in the calculation from one case study to another. Input data defined in this subprogram are:

IEND : total number of iterations
IPRINT: number of iterations before printing
STESIZ: time step (s)
DELL : horizontal grid interval (cm)
DELZ : vertical grid interval (cm)
KM : horizontal momentum viscosity (cm^2/s)
KT : horizontal thermal conductivity (cm^2/s)
LATD : latitude of the reference station in degrees portion
LATM : latitude of the reference station in minutes portion
ZS : terrain heights (ft) of each grid point in the study domain
ZO : roughness lengths (cm) of each grid point in the study domain
WW : water fraction of each grid point in the study domain
TWATER: water temperature (^oC)
YREF : y-coordinate of the reference station
XREF : x-coordinate of the reference station

READ2 provides meteorological input data specific to the case being studied. Input data include:

P : surface pressure (mb) at the reference station
DELP : surface pressure gradient (mb) at the reference station
DELS : surface isobar spacing (lat)
DPA : surface isobar angle
DATE : 16-character title describing the time and date of this study case
Z85 : 850 mb height (m)
DELZ85: 850 mb contour gradient (m)
DELS85: 850 mb contour spacing (lat)
DZ85A : 850 mb contour angle
T85 : 850 mb temperature (^oC)
TREF : surface temperature (^oC) at the reference station
ZREF : terrain height (m) of the reference station
Z70 : 700 mb height (m)
T70 : 700 mb temperature (^oC)

Note that after a case study has been run, the program will return to READ2 and attempt to read another set of input data for the next case study. If there is no other set of input data, the program will simply terminate.

READ3 provides the coordinate data for each of the reference stations. The following input data are given in this subprogram:

M1 : the number of reference stations for which input data are available
YSTN : y-coordinate of that reference station
XSTN : x-coordinate of that reference station

With the above modifications, the input data files are simpler and easier to operate and understand.

The next modification is performed to reduce storage space requirements in the model. In the first, arrays that are used in

only a small number of subprograms are placed in an area of COMMON that is not needed at the time. The size of arrays which do not use the outer row and column of data, such as VNEW (the predicted wind speed), is reduced to the minimum.

These modifications were performed on the Atmospheric Research Section's HP1000 minicomputer system. EMA, an extended memory area facility, was used to enhance the efficiency of the calculation. However, this EMA facility is not needed on the UNIVAC system. A detailed documentation of the computer program is given in Appendix A.

4.0 DISCUSSION OF RESULTS

4.1 Input Data

The model described in the previous section has been applied to simulate the surface wind field on April 2 and 3, 1982 and on February 9, 1984. The simulations for April 2 and 3, 1982 were performed for six time periods with a six-hour time interval. These time periods are 0700, 1300 and 1900 EST on April 2 and 0100, 0700 and 1300 EST on April 3. The simulation for February 9, 1984 was performed for the 0100 EST period.

The input data for the seven simulations are listed in Table I. These input data were obtained from the weather maps except the lake surface temperature which is assumed to be constant throughout these case studies. An example of the input data file is given in Appendix B.

4.2 Model Simulated Winds

Figure 5 displays the surface wind field simulated by the model at 0700 EST, April 2, 1982. The winds are generally northwesterly and the wind speeds vary from about 2.5 m/s over the land surface to about 6.0 m/s over the lake. Weaker winds over the land surface may be attributed to the surface friction and the microscale effects of the local terrain.

Figure 6 shows the simulated wind at 1300 EST, April 2, 1982. The winds were from the southeast. Again, the wind speeds in this case were weaker over the land than over the lake. However, the wind speed increased in response to the diurnal heating. The magnitude ranged between 3 and 4 m/s over the land and 5 and 6 m/s over the lake.

The simulated surface winds at 1900 EST, April 2, 1982 are displayed in Figure 7. It can be seen that the southerly component of the wind was less significant in this case. The general air flow was from the east. The wind speeds over the land and over the lake were about 5.5 m/s and 8.5 m/s, respectively.

The simulated wind field at 0100 EST, April 3, 1982 is presented in Figure 8. The winds were generally from the southwest. Slight veering was evident along the lakeshore area. The wind speed was about 3.5 m/s over the lake and 2.0 m/s over the land.

TABLE I

INPUT DATA FOR SURFACE WIND SIMULATIONS AT THE PICKERING AREA

Reference Station	Toronto International Airport (43°48'N)						
Date	April 2'82				April 3'82		Feb 9'84
Time (EST)	0700	1300*	1900	0100*	0700	1300*	0100
Sea Level Pressure (mb)	1025.8	1023.5	1017.7	1006.8	992.9	983.5	1020.9
Sea Level Isobar Spacing (° lat)	2.5	2.0	1.3	2.5	1.1	1.1	1.5
Sea Level Isobar Angle	340	145	130	170	130	210	260
Surface Temperature (°C)	-4	1	1	1	3	14	-7
Lake Temperature (°C)	0	0	0	0	0	0	0
950 mb Height (m)	1548	1548	1548	1539	1530	1521	1440
850 mb Contour Spacing (° lat)	4.5	5.0	5.0	3.0	1.5	1.0	2.0
850 mb Contour Angle	335	270	190	200	210	210	320
850 mb Temperature (°C)	-2	2	7	8	10	12	-9
700 mb Height (m)	3020	3030	3040	2965	2890	2880	2940
700 mb Temperature (°C)	-6	-4	-2	0	1	5	-15

* extrapolated between the time periods for which weather maps are available

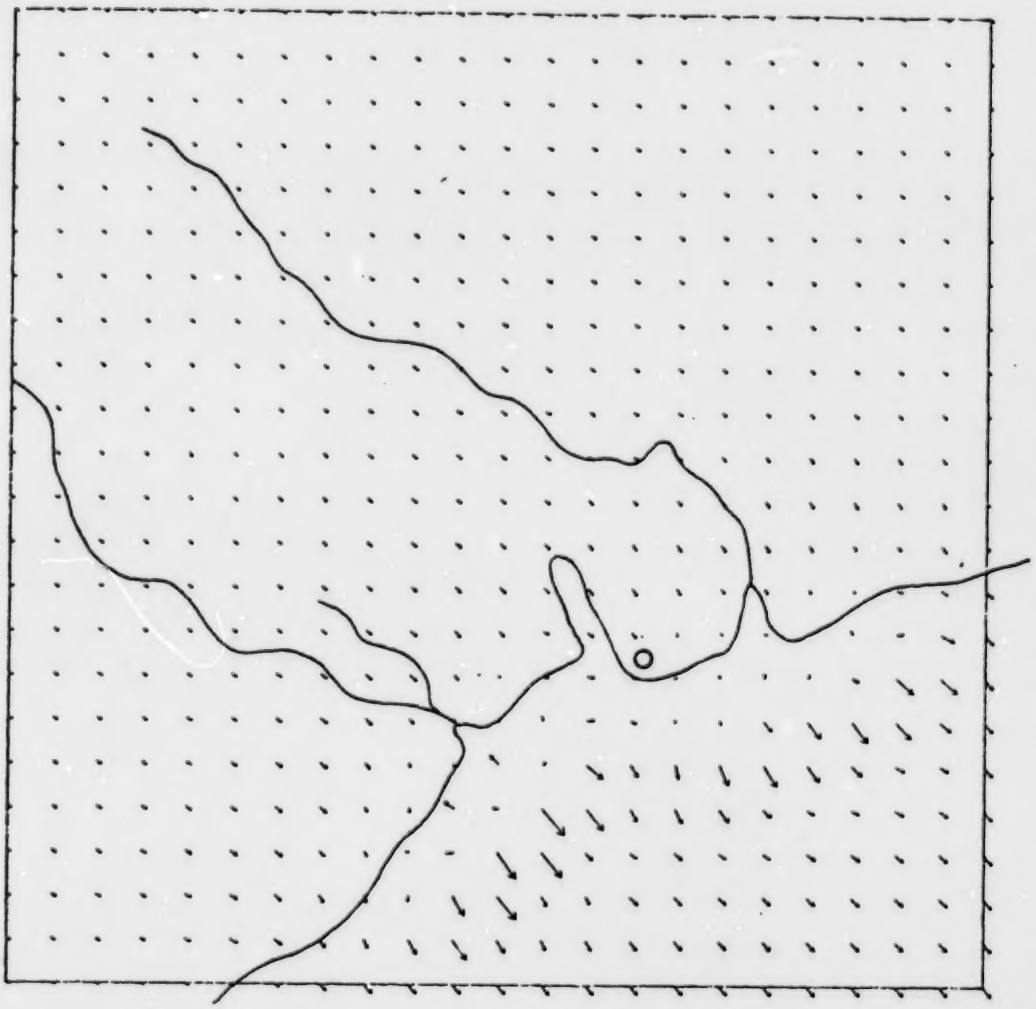

FIGURE 5

THE SIMULATED SURFACE WIND FIELD AT 0700 EST,
APRIL 2, 1982

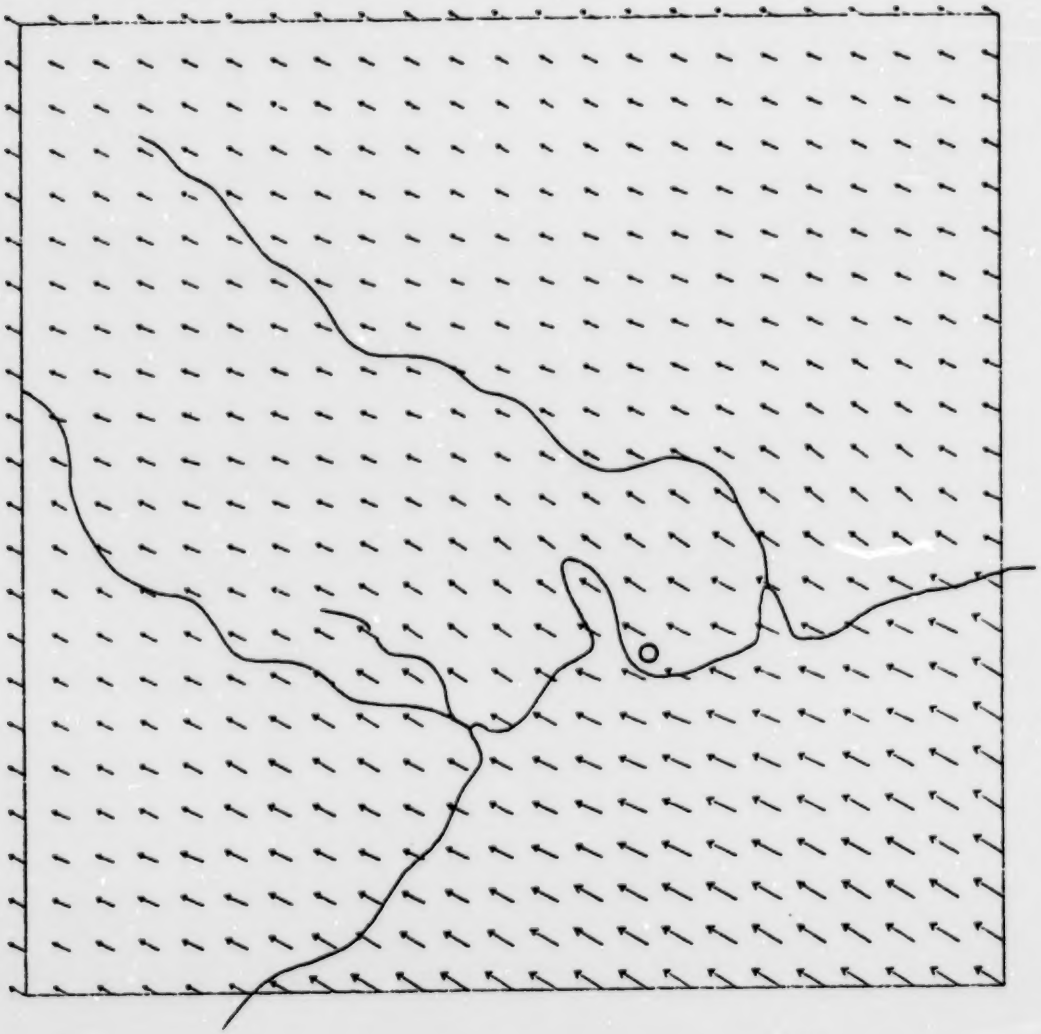

FIGURE 6

THE SIMULATED SURFACE WIND FIELD AT 1300 EST,
APRIL 2, 1982

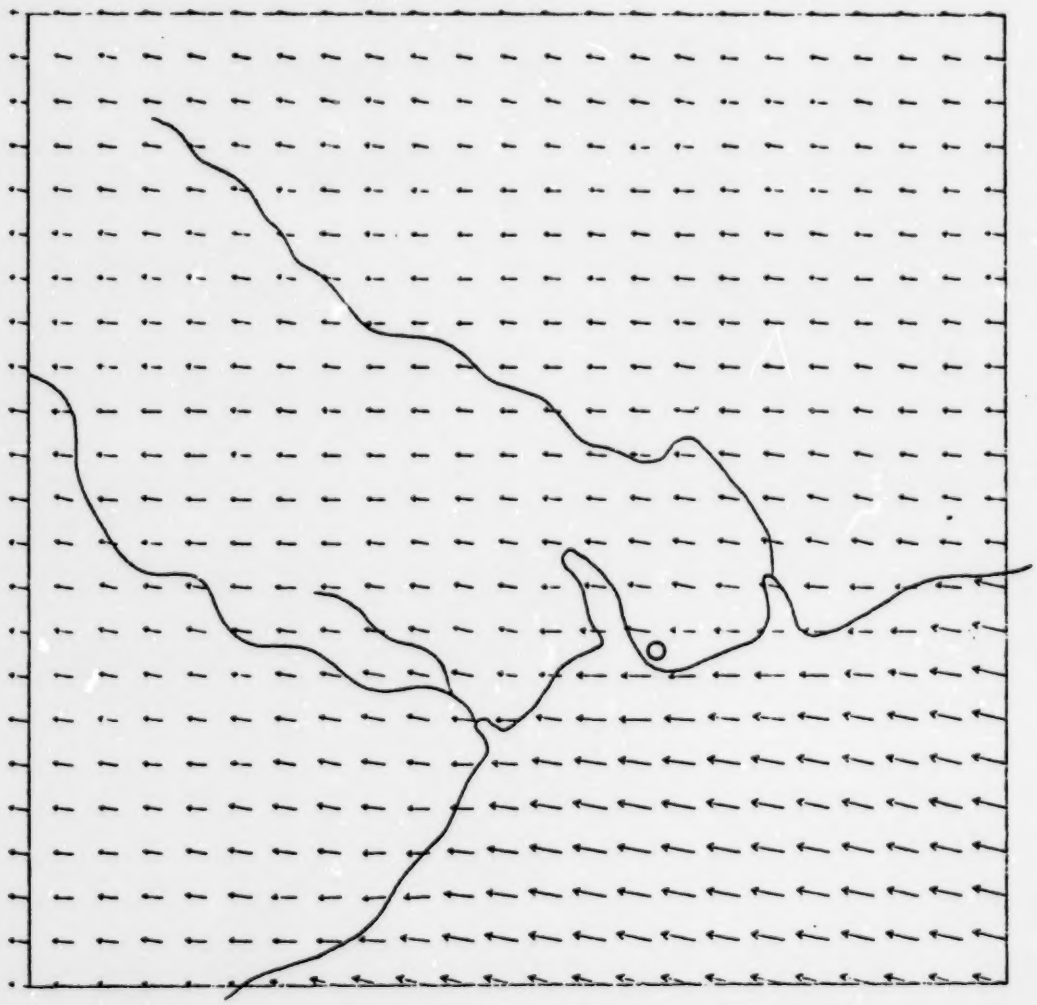

FIGURE 7

THE SIMULATED SURFACE WIND FIELD AT 1900 EST,
APRIL 2, 1982

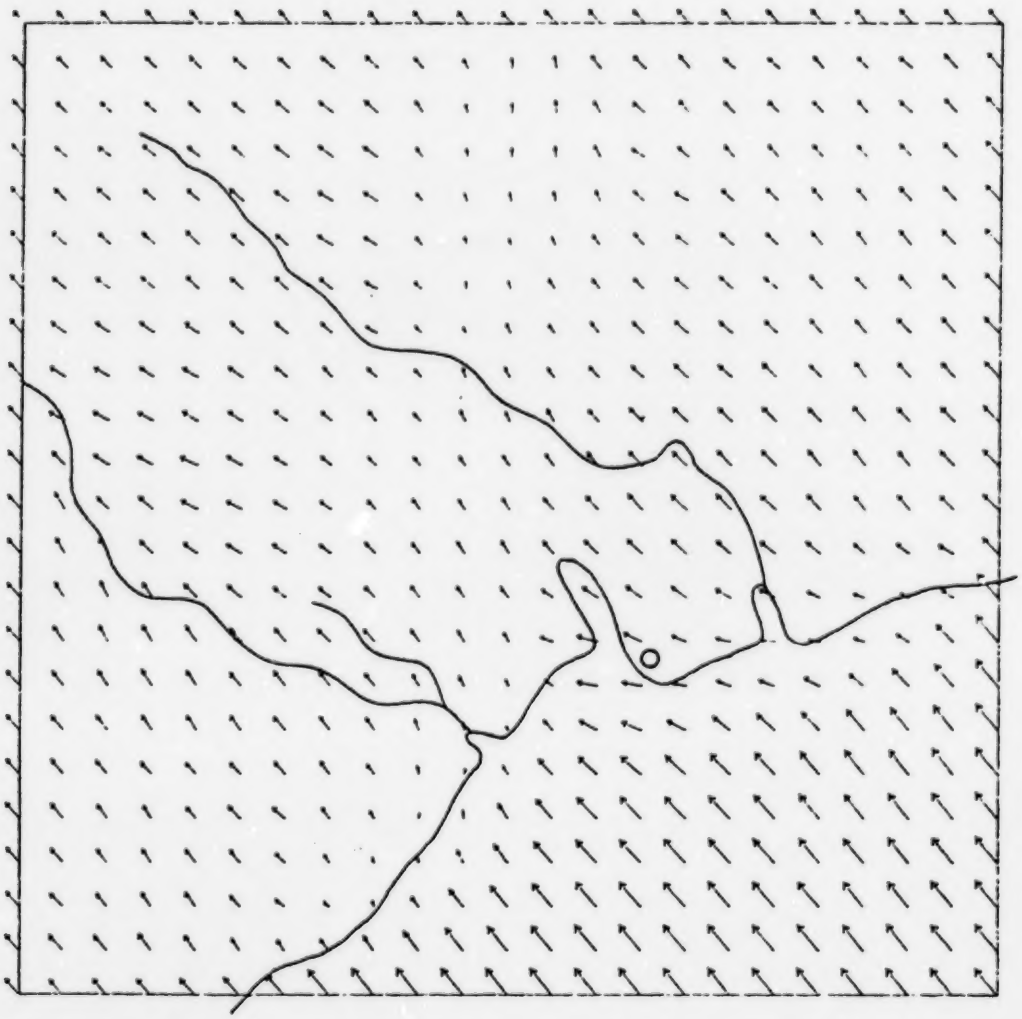

FIGURE 8

THE SIMULATED SURFACE WIND FIELD AT 0100 EST,
APRIL 3, 1982

At 0700 EST, April 3, 1982 (Figure 9), the simulated winds were from the east-southeast and the wind speeds increased due to surface heating. Variations of wind direction were also observed along the shoreline area. The wind speed in this case was about 10 m/s over the lake and 7 m/s over the land.

The next case (Figure 10) shows the simulated winds at 1300 EST, April 3, 1982. Except at the lakeshore area, the simulated winds were quite uniform and were from the south with a speed of about 10 m/s over the study domain. Veering was observed along the shoreline in the Pickering area. This feature may be due to the development of the lake breeze.

Figure 11 displays the surface wind field at 0100 EST, February 9, 1984. The general winds were from the west-southwest. The wind speeds of about 5.5 m/s over the land were weaker than those of about 12 m/s over the lake.

4.3 Comparison With Observations

Table II lists the observed and simulated surface winds at Pickering NGS for the seven selected cases. In general, the simulated winds agree quantitatively with the observed values. The model produces correctly the wind directions and the diurnal variation of the surface wind, ie, increase in speed during daytime hours and decrease in speed during nighttime.

However, the simulated wind speeds show differences from the observed values. The greatest differences occurred at 0100 EST, April 3, 1982 and at 0100 EST, February 9, 1984. Note that these differences are prominant at times when the upper level weather data are not available.

Observed vertical wind profiles were not available for comparison in the Pickering area. However, using wind data observed at the Evans Avenue Meteorological Tower on February 9, 1984 (see Table III), it can be revealed that there were similarities in both locations.

5.0 CONCLUDING REMARKS

The surface wind model of the SASDOC computer program has been optimized for the Pickering area. This optimization included modifications of the model itself and the input data files and the incorporation of the microscale features of the Pickering area. With these modifications, the time resolution of the surface wind calculations and the execution time of the calculation have been improved. As well, similarity equations were implemented to calculate the vertical wind profiles.

The model has been applied to simulate the surface wind fields on April 2 and 3, 1982 and on February 9, 1984 over the Pickering region. The simulated results were compared with observed values at seven time periods. It was concluded that the model was most successful in simulating the wind direction and the diurnal variation of the surface wind; but less successful in simulating the magnitudes of

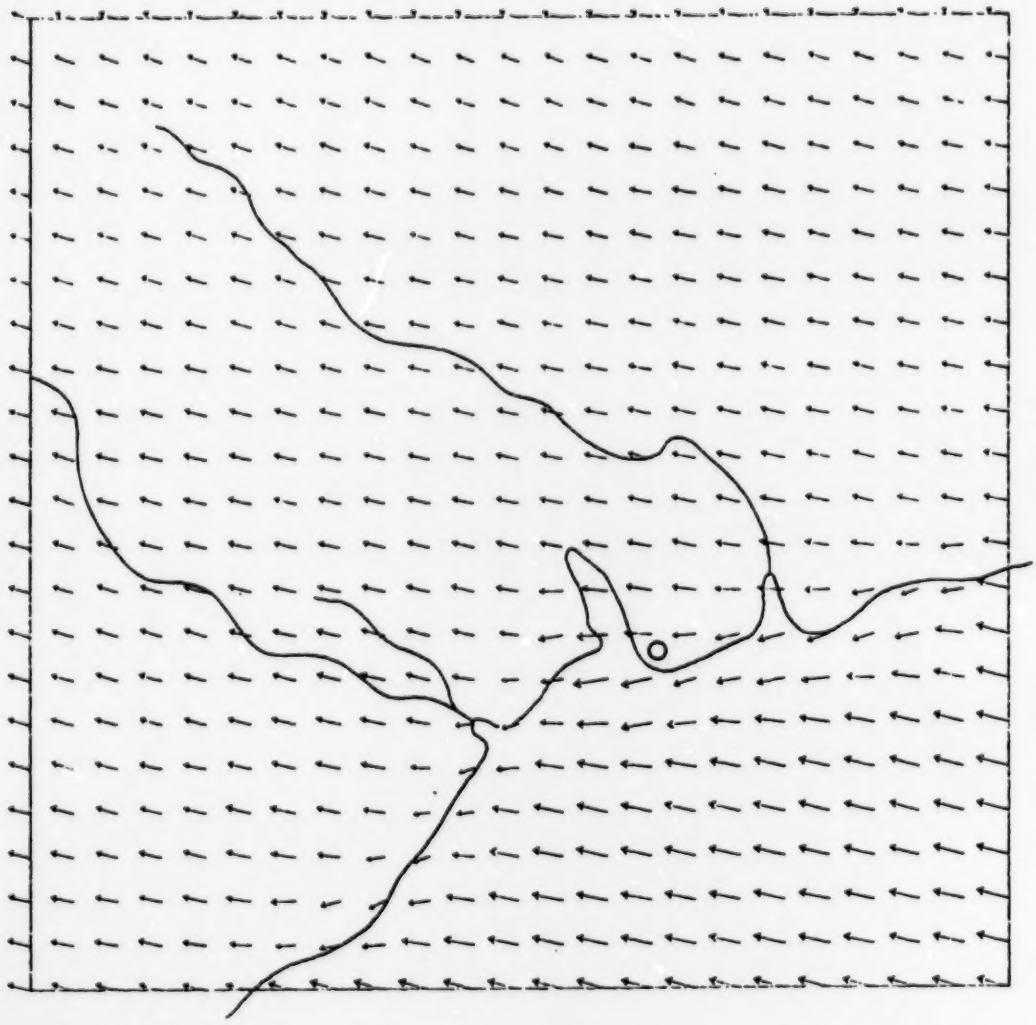

FIGURE 9

THE SIMULATED SURFACE WIND FIELD AT 0700 EST,
APRIL 3, 1982

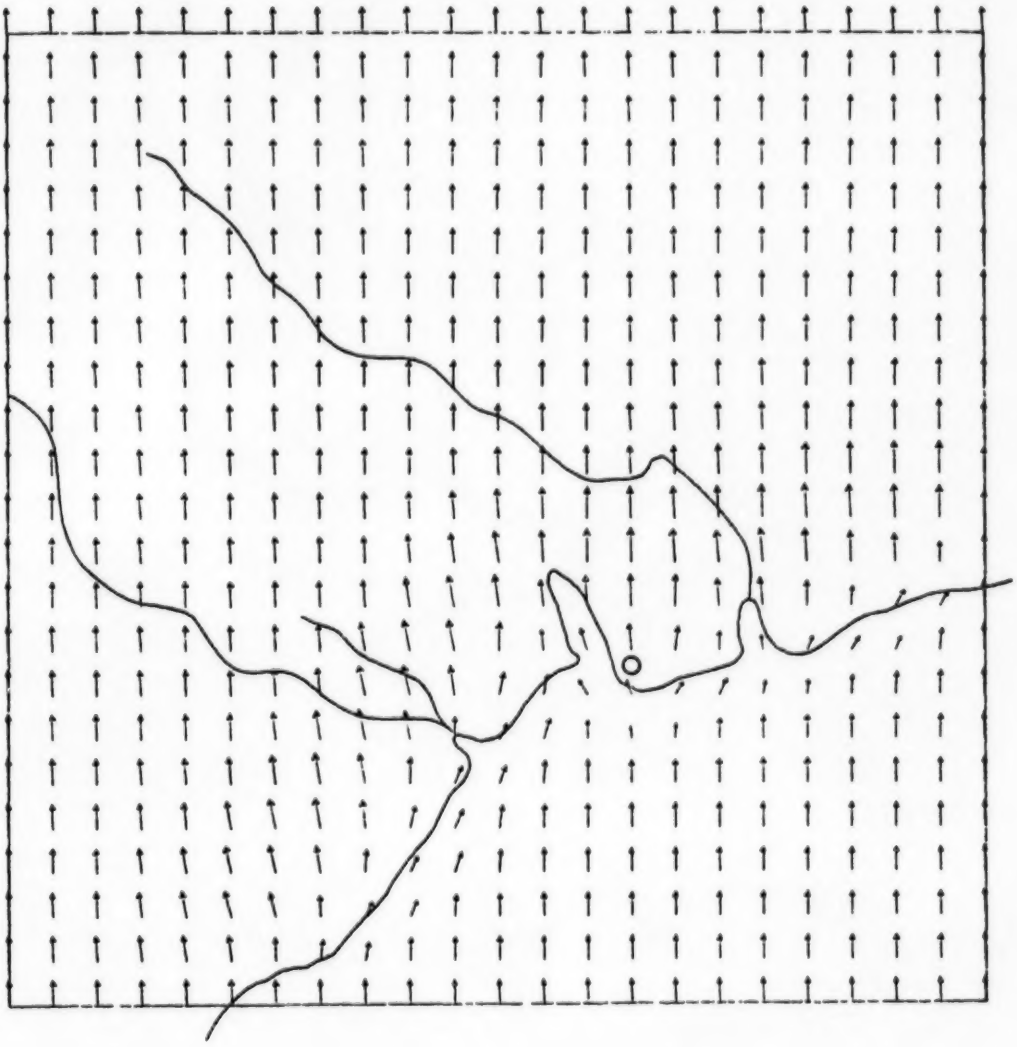

FIGURE 10

THE SIMULATED SURFACE WIND FIELD AT 1300 EST,
APRIL 3, 1982

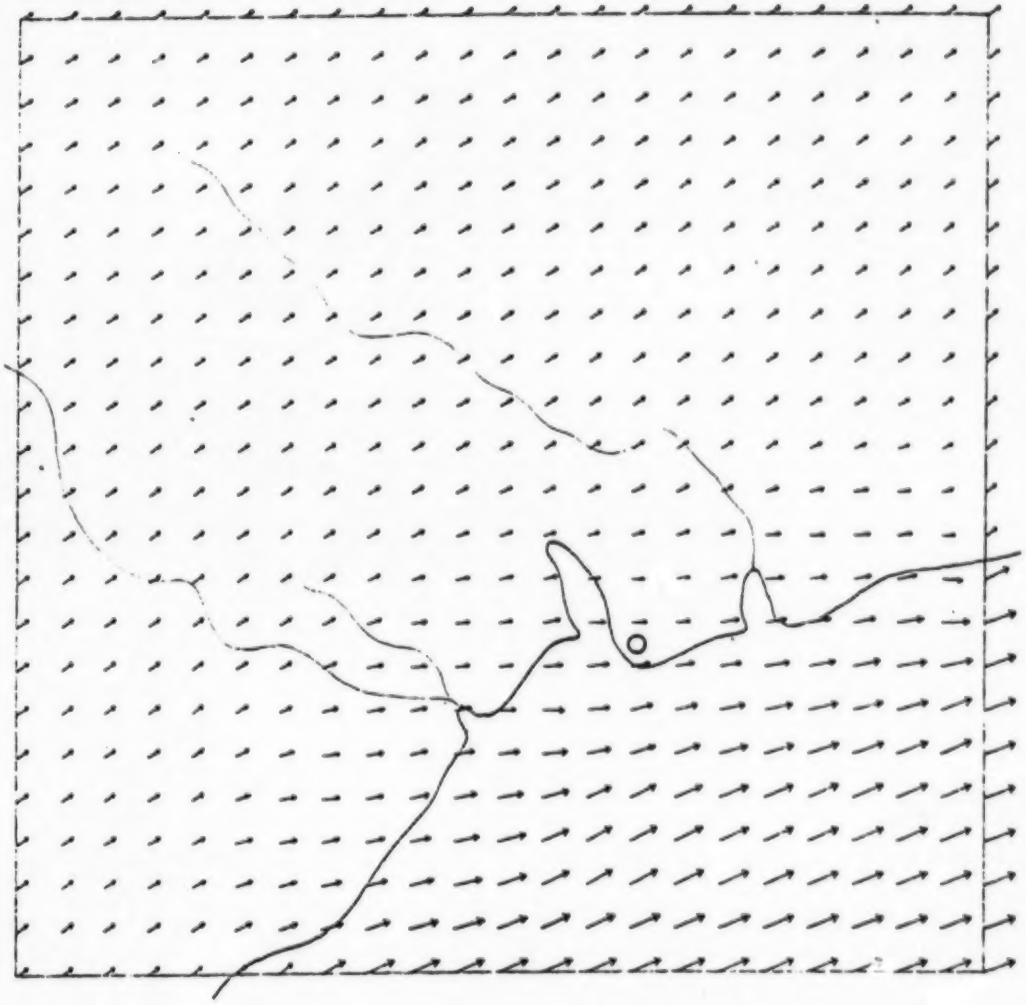

FIGURE 11

THE SIMULATED SURFACE WIND FIELD AT 0100 EST,
FEBRUARY 9, 1984

TABLE II

COMPARISON OF THE OBSERVED AND SIMULATED SURFACE WINDS AT PICKERING NGS

	Observed Wind		Simulated Wind	
	Speed (m/s)	Direction	Speed (m/s)	Direction
April 2'82				
0700 EST	1.6	314	2.4	312
1300 EST	4.3	160	4.6	116
1900 EST	8.4	108	7.0	94
April 3'82				
0100 EST	11.6	94	2.4	107
0700 EST	10.5	91	8.9	86
1300 EST	5.4	194	8.3	168
Feb 9'84				
0100 EST	3.3	WNW	6.7	263

TABLE III

COMPARISON OF THE OBSERVED AND SIMULATED VERTICAL VELOCITIES AT 0100 EST, FEBRUARY 9, 1984

Height	Observed at Evans Ave Tower	Simulated at Pickering NGS
10 m	3.8 m/s	3.06 m/s
32 m	5.7 m/s	5.05 m/s
85 m	7.7 m/s	8.86 m/s

surface wind speed. This may be in part due to the effects of local terrain. Note that the observed wind data at the Pickering NGS were obtained from an on-site meteorological tower. This tower is located very close to a mound whose height is slightly higher than the anemometer level. Thus, influences due to the local microscale effects are expected in the observed winds. Another reason may be the upper level input data, since the 850 and 700 mb weather maps are only available every twelve hours.

The similarity vertical wind profiles are considered to be valid up to about 100 m in height. Above this level, a geostrophic adjustment such as that suggested by Csanady (1972) may be used. Observations by other means, eg, releases of PIBAL minisondes, are also recommended to obtain data for fine tuning of the model.

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POOR

QUALITY

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